

RETRIEVAL OF OCEAN SURFACE WINDSPEED AND RAINRATE FROM THE HURRICANE IMAGING RADIOMETER (HIRAD) BRIGHTNESS TEMPERATURE OBSERVATIONS

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1. INTRODUCTION

The Hurricane Imaging Radiometer (HIRAD) is a new airborne synthetic aperture passive microwave radiometer capable of wide swath imaging of the ocean surface wind speed under heavy precipitation e.g. in tropical cyclones. It uses interferometric signal processing to produce upwelling brightness temperature (T_b) images at its four operating frequencies – 4, 5, 6 and 6.6 GHz [1,2]. HIRAD participated in NASA's Genesis and Rapid Intensification Processes (GRIP) mission during 2010 as its first science field campaign. It produced T_b images with ~70 km swath width and 3 km resolution from a ~ 20 km altitude. From this, ocean surface wind speed and column averaged atmospheric liquid water content can be retrieved across the swath. The column averaged liquid water then could be related to an average rain rate. The retrieval algorithm (and the HIRAD instrument itself) is a direct descendant of the nadir-only Stepped Frequency Microwave Radiometer that is used operationally by the NOAA Hurricane Research Division to monitor tropical cyclones [3,4]. However, due to HIRAD's slant viewing geometry (compared to nadir viewing SFMR) a major modification is required in the algorithm. Results based on the modified algorithm from the GRIP campaign will be presented in the paper.

2. RETRIEVAL ALGORITHM

The retrieval algorithm uses a forward radiative transfer model to simulate T_b's at all 4 HIRAD frequencies over a wide range of possible wind speeds and rain rates. The wind speed and rain rate combination that produces minimum error between the modeled and the measured T_b's for all four frequencies is chosen to be the solution [5]. The SFMR-based algorithm, which treats each pixel to be independent, works for HIRAD along-track pixels. However, for the cross-track pixels this assumption is not valid because of the slant look angle. The effect is stronger in the far off-nadir pixels. Thus it is necessary to establish an accurate forward model and innovate a retrieval approach that considers atmospheric contribution from all the pixels in the HIRAD viewing path.

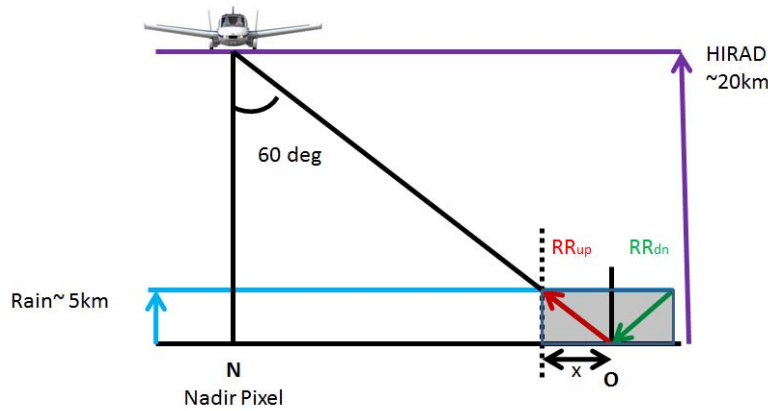


Figure 1: HIRAD viewing geometry

2.1. HIRAD Geometry

Even though HIRAD is built primarily to measure hurricane force wind speed, the forward radiative transfer model based retrieval algorithm requires an accurate estimation of the column averaged atmospheric liquid water content in the HIRAD viewing path to minimize the error in wind speed retrieval. In figure 1 a typical HIRAD viewing geometry is described where the instrument is flying at an altitude of $\sim 20\text{km}$ and the freezing height of rain is assumed to be $\sim 5\text{km}$. Let us consider the retrieval at a pixel O (off-nadir angle of 60 degree) where the observed T_b has atmospheric contribution from the entire shaded region of the figure 1. The version 0 algorithm assumes a uniform rain rate (RR) in the shaded region and thus introduces systematic error that varies from scene to scene depending on the inhomogeneity of the RR within $\pm x$ km from pixel O. For the case in figure 1, the distance x is ~ 8.66 km.

This phenomenon was best observed in an attempt to simulate brightness temperature across the HIRAD swath using retrieved geophysical parameters (wind and rain) from SFMR during a HIRAD-SFMR cross-over in hurricane Earl on September 01, 2010, as a part of GRIP campaign. As SFMR flew westward over a north-bound HIRAD swath (figure 2) located west to the storm center, it took measurements of the surface wind speed and rain rate along all the cross-track pixels in HIRAD swath. The SFMR measurements being within less than 30 minutes of HIRAD overpass enabled us to accurately represent geophysical fields seen by HIRAD. The top left hand side panel of figure 2 shows SFMR-retrieved wind speed (black) and rain rate (green) offset by 50 in their respective units of m/s and mm/hr respectively. From these geophysical fields, using the T_b forward model for the version 0 algorithm produced the T_b 's represented by 'thin' red (4 GHz) and blue (5 GHz) lines in the same figure. The actual HIRAD observations represented by the respective 'thick' line plots follow the simulations closely except the strong double rain features in the simulation created by the rain on the east-side of the swath is broadened to a single feature in the HIRAD observation.

The reason for such an anomaly is explained in figure 3, where the variation of viewing angle (in deg)

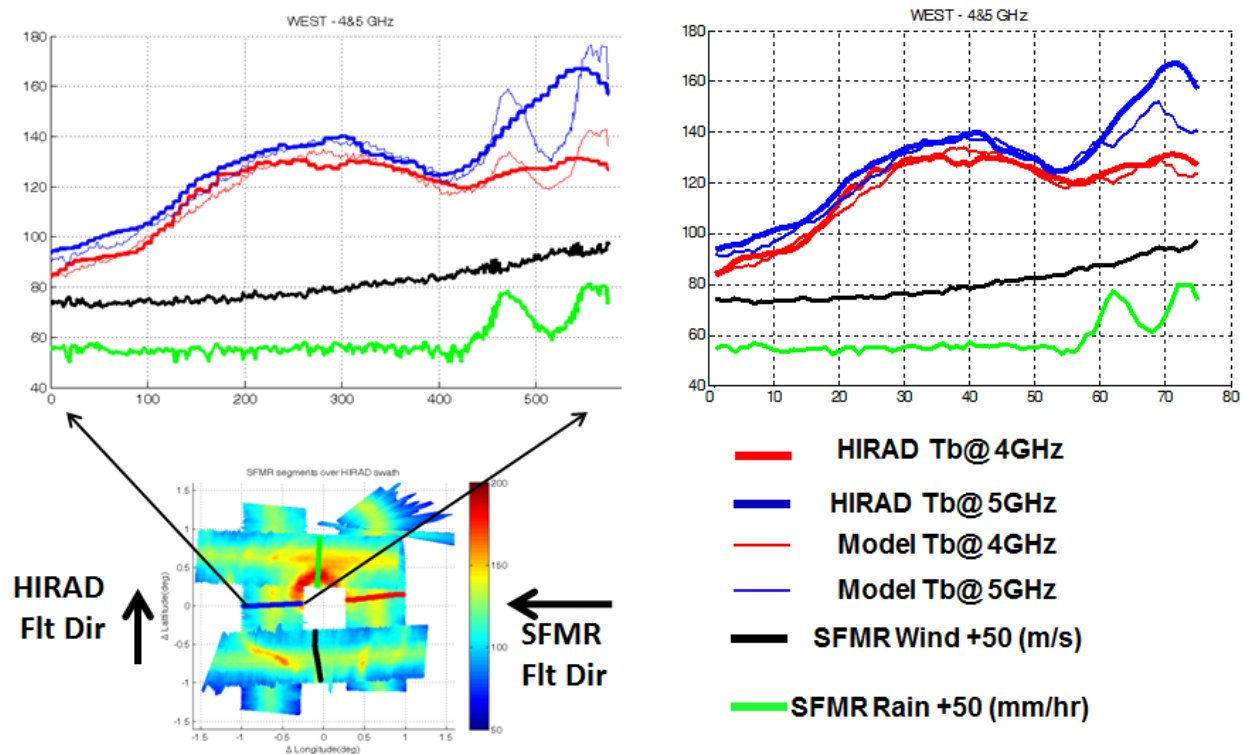


Figure 2: Simulation of HIRAD Tb from SFMR retrievals. v0 forward model (top left panel) & modified model (top right panel)

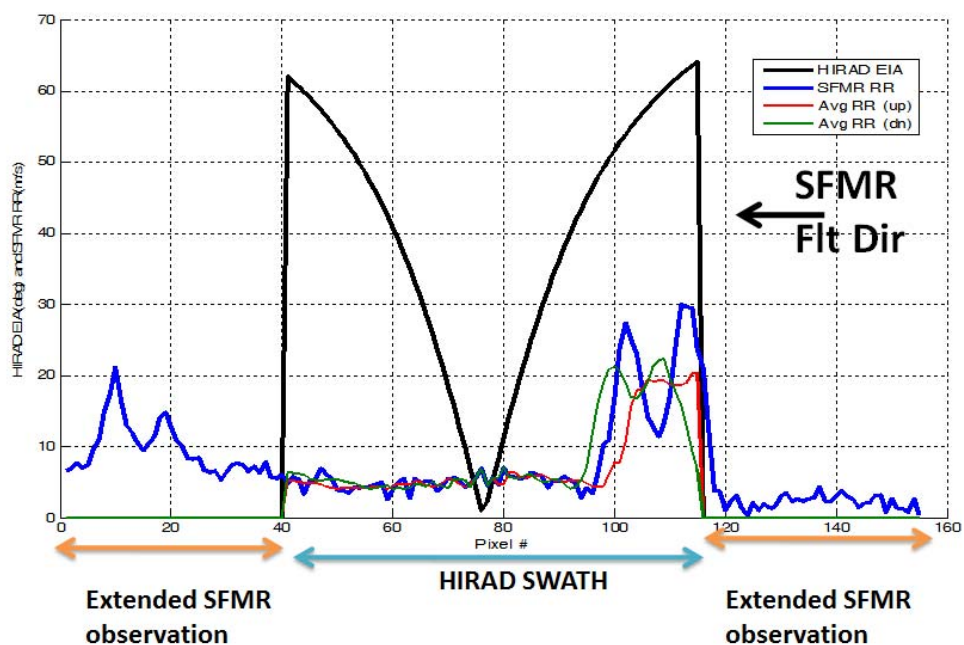


Figure 3: Rain rate decomposition into upwelling and downwelling paths in the modified forward model

across the HIRAD swath is plotted by the black line. The blue line is the SFMR observed rain rate in mm/hr. Instead of the assumption of homogeneous uniform average rain rate field (and assuming it to be equal to ‘blue’ line) the average rain encountered by HIRAD beams are separated into upwelling (red) and downwelling (green) components. Several features in these components are noteworthy. For example around pixel# 95, the rain at pixel# 100 has started to show up through the downwelling path. Tb simulations from the modified forward radiative transfer model, which uses two separate components of average rain-rate computed based on the viewing geometry, is shown in the top right hand panel of figure 2. The simulations (‘thin’ blue and red line) seem to explain Tb’s observed by the HIRAD instrument (corresponding ‘thick’ lines).

HIRAD antenna is designed to filter only the horizontal polarization (H-pol) component of the upwelling Tb’s. In general upwelling path average rain will have a stronger effect than the downwelling path as the latter is multiplied by the surface reflectivity (a factor less than 1). At H-pol, however, surface reflectivity increases with incidence angle, thus increasing the downwelling contribution at the edge of swath. Furthermore, the effect of cross-pol must be considered in the retrieval algorithm.

3. REFERENCES

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